

Opportunities for Precision Tests of Three-Neutrino Mixing and Beyond with LBNE

The LBNE collaboration

The Long-Baseline Neutrino Experiment (LBNE) plans a comprehensive program that will characterize neutrino oscillation phenomenology using a high-intensity accelerator neutrino beam, a 1300 km baseline, and a massive liquid argon TPC as the far detector. The goals for this program are the explicit demonstration of leptonic CP violation, determination of the neutrino mass hierarchy (MH), precision measurement of neutrino oscillation parameters, search for new physics that would reveal itself as deviations from the expected three-flavor neutrino oscillation model, and underground physics, including the exploration of proton decay and supernova neutrinos. The key elements of LBNE are 1) an optimum baseline from the neutrino source to the detector, 2) a large and highly capable far detector, 3) a high power, broadband, sign selected muon neutrino beam, and 4) a capable near neutrino detector. The far detector should be placed at sufficient depth to suppress cosmic ray backgrounds to negligible level, and if placed deep enough will provide unparalleled sensitivity to proton decay and astrophysical sources of neutrinos.

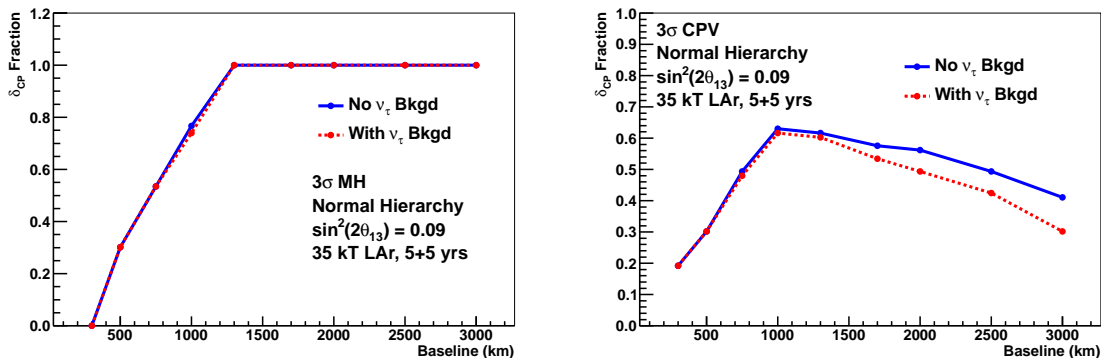


Figure 1: Fraction of covered CP phase at 3σ for mass hierarchy determination (left), and for CP violation (right).

Optimization of the baseline to determine the MH and CP violation with no ambiguities depends only on the known oscillation parameters. To determine the MH over all phase space requires a baseline >1000 km, and the optimum for determining CP violation is near 1300 km[1](Fig. 1) regardless of the MH determination. A 35 kt fiducial mass LAr TPC was chosen for the far detector due to four key advantages: excellent particle ID and high efficiency for ν_e events, sensitivity to SUSY-inspired proton decay modes ($p \rightarrow K^+\bar{\nu}$), sensitivity to supernova neutrinos, and modularity which allows flexibility in the construction. In addition, the LArTPC is relatively insensitive to depth for accelerator neutrino physics[2]. The full scope of the scientific program requires placing the detector deep to eliminate cosmogenic backgrounds[3]. The near detector is discussed in another white paper[4].

Following many years of study [5], the 2008 P5 report recommended a “world-class neutrino program as a core component of the U.S. program...” with a detector at the proposed DUSEL¹ and a high intensity neutrino source at Fermilab. In January 2010, the DOE approved the Mission Need for LBNE[6]. The discovery of non-zero θ_{13} has made the scientific opportunity very important and has removed any uncertainty in the viability of such a program. In 2012, in response to the call from DOE for a phased approach to LBNE, an external panel endorsed the overall strategy for LBNE with a 1300 km baseline and recommended a Phase 1 configuration that fit the budget guidance[1]. Recently, the European Strategy Group declared long-baseline oscillations as one of the four high priority large-scale scientific activities for the future [7].

LBNE will be a phased program with increased scientific capabilities at each phase. *The goal of the first phase is to construct a broadband beam capable of 2.3 MW operation, a greater than 10 kt underground far detector, and a near neutrino detector.* The current funding guidance from DOE allows for construction of the beam-line, tertiary muon detectors to monitor the beam and a large liquid argon TPC on the surface at SURF. Underground placement, the near detector, and some beam-line enhancements are expected to be enabled by non-DOE sources. This selection secures in the first phase the truly unique aspects of LBNE, the near optimum 1300 km baseline and the high power broadband beam. DOE approved CD-1 for the first phase of LBNE in December 2012.

The total event rate for LBNE without oscillations will be about 3000 (1000) events/MW/10kt/yr from the neutrino (antineutrino) beam. Oscillations will produce a distinctive structure in the energy spectrum of these events. Oscillations of $\nu_\mu \rightarrow \nu_e$ with $\theta_{13} = 9^\circ$ will produce about 70 ν_e (25 $\bar{\nu}_e$) reconstructed events/MW/10kt/yr from the ν_μ ($\bar{\nu}_\mu$) beam. The anticipated rate asymmetries in the observed ν_e vs. $\bar{\nu}_e$ spectra are 30 – 50% due to the CP phase and the matter effect. Figure 2 shows the sensitivity to CP from the LBNE program by fitting the expected spectra. In the first phase, LBNE achieves complete coverage of the parameter space for MH determination in combination with other data, and measures the CP phase to $\pm(20^\circ - 35^\circ)$. The design of LBNE allows measurement of the CP phase with uncertainty of $\pm(5^\circ - 10^\circ)$ with a large detector and 2.3 MW beam power, and provides the best potential for discoveries of non-standard interactions beyond the standard three-flavor model [8].

¹now the Sanford Underground Research Facility (SURF)

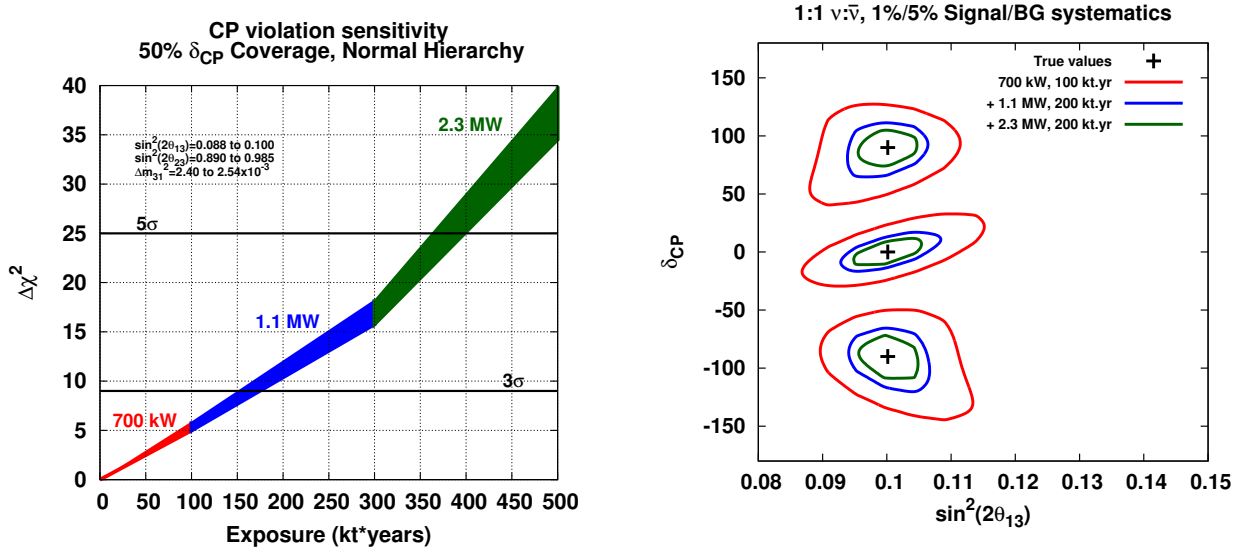


Figure 2: Left: Sensitivity to CP violation as a function of exposure with equal parts ν and $\bar{\nu}$ running. The MH is assumed to be unknown and determined in the same experiment. Right: Measurement (1σ) of θ_{13} and δ_{CP} at the end of each of the indicated phases.

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